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Divisions of Plant Pathology and Agronomy

The Control of Bunt or Stinking Smut of Wheat

by

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THE CONTROL OF BUNT OR STINKING SMUT OF WHEAT

F. D. Heald and E. F. Gaines

INTRODUCTION

Two species of bunt or stinking smut of wheat have long been known in various parts of the world, but previous to 1918 the predominating species in Washington was the rough-spored species, *Tilletia tritici*. During 1919 an extensive survey was made of 631 fields in the wheat districts of the state and only two fields were found in which the smooth-spored species, *T. levis*, was present, one in Lincoln County and one in Island County. In 1927 and in 1928 a systematic survey was again made of the wheat districts of eastern Washington to ascertain the distribution of the two species of bunt, in 1927 by the examination of a large collection of warehouse samples and in 1928 by the collection of specimens direct from the field (10). The examination of these collections has shown that although *T. tritici* continues to be the predominating species, the smooth-spored species, *T. levis*, was found to be present in all the principal wheat-growing sections of eastern Washington (Fig. 1). In fields of Turkey, Albit and Ridit, *T. levis* is often the only species to be found.

Faris (2) in 1924 published the first evidence of physiologic forms of bunt. Reed (12) found ten forms, four of *T. levis* and six of *T. tritici*. Five collections were from various places in the United States and five from Europe.

Rodenhiser and Stakman (13) compared the virulence of several collections of smut from Europe with the local Minnesota smut on the three wheats, Kota, Marquis and Einkorn. New forms were obtained from Norway, New Zealand and Hungary. Gaines (3) obtained a smut collection from Germany that was particularly virulent on Turkey. Martin and

White Odessa. Dillon-Weston (1) presented evidence that new forms could be isolated from the common smut in England by using hosts resistant to the prevailing form.

In 1927 evidence was obtained in both Washington and Oregon that new forms of stinking smut had appeared that would attack hitherto resistant varieties of wheat. Microscopic examination and subsequent tests in 1928 and 1929 have shown that there are at least seven forms that differ in their power to infect certain wheats (Table 1). Three of these belong to the rough-spored species, *Tilletia tritici*, and four to the

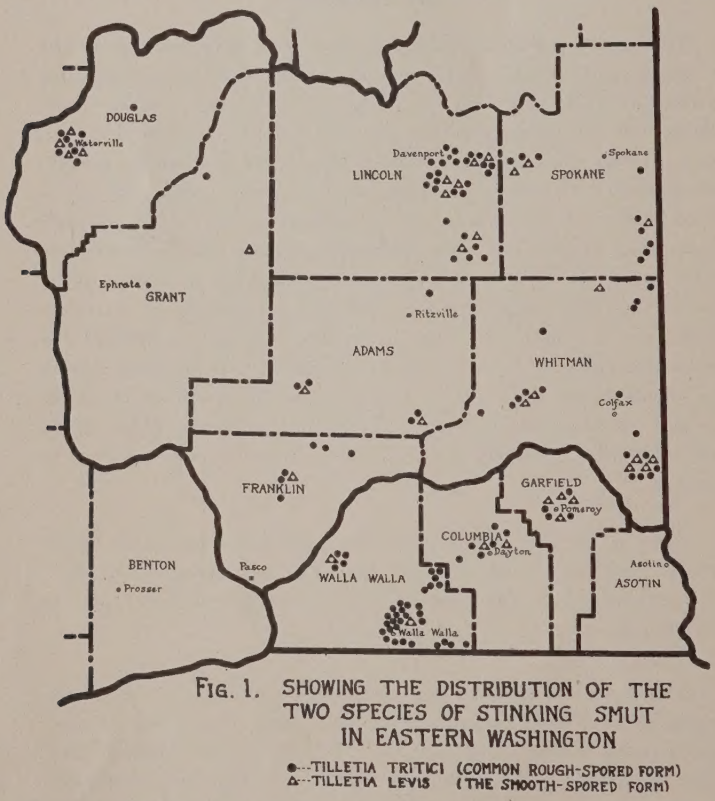

Fig. 1. Distribution of the two species of stinking smut in eastern Washington (After Kienholz and Heald).

smooth-spored species, *T. levis*. The varieties of Turkey winter wheat are especially susceptible to five of them. Ridit is the only common winter wheat that shows resistance to all of them. Marquis of the spring wheats is also more or less resistant to all forms. Hybrid 128 and Jenkin are susceptible to all seven forms.

The spread of these new forms makes seed treatment even more necessary than before, especially with wheats that were highly resistant

Table 1. Percentage of Smutted Heads Produced on 22 Wheats from Inoculum of 7 Physiologic Forms (T-1, T-2, T-3—Tilletia tritici, and L-4, L-5, L-6, L-7,—Tilletia levis.)

Variety	Physiologic form of inoculum used on seed							
	T-1	T-2	T-3	L-4	L-5	L-6	L-7	Av.
Winter wheat sown September 9								
Hybrid 128	68.	83.	90.	84.	90.	78.	80.	82.
Turkey	6.	86.	2.	71.	72.	62.	71.	53.
Martin	0.	19.	71.	51.	0.	49.	62.	36.
Ridit	0.	2.	0.	0.5	3.	3.	14.	3.
Hussar	0.	25.	0.	35.	0.	37.	45.	20.
White Odessa	0.	86.	80.	70.	2.	75.	83.	57.
Albit	0.	75.	77.	44.	0.	45.	72.	45.
Hohenheimer	0.6	4.	0.4	0.	2.	0.1	0.	1.
Oro	0.8	0.4	0.	0.1	0.6	2.	0.4	0.6
Hope	51.	60.	42.	61.	78.	40.	59.	56.
Average	12.6	44.0	36.2	41.7	24.8	39.1	48.6	35.3
Spring wheat sown April 24								
Baart X Ridit	0.	0.6	0.	6.	0.	2.	4.	1.8
Ridit X Bluestem	0.	0.8	0.	0.	0.3	1.	0.	0.3
Bluestem X Hussar	0.	3.	4.	0.9	1.	4.	0.3	1.9
Martin X Marquis	2.	8.	21.	0.	25.	2.	2.	8.6
Marquis X Florence	5.	5.	4.	0.3	1.	0.4	0.	2.2
Marquis X Turkey	0.	0.	0.	1.	7.	9.	6.	3.3
Jenkin	92.	78.	73.	58.	56.	48.	34.	62.7
Hope	0.	0.	0.	0.	0.	0.	0.	0.
Alaska	0.7	0.	0.	0.	0.	0.	0.	0.1
Marquis X Turkey *	2.	6.	4.	0.	2.	0.4	3.	2.5
Lutescens	2.	2.	0.	3.	3.	0.5	1.	1.6
White Russia	6.	5.	13.	2.	10.	8.	2.	6.6
Average	9.1	9.0	9.9	5.9	8.8	6.3	4.4	7.6

* This was grown under the name "Quality" but it was distinctly not Quality. From its performance it seems certain that it came from a plant selection of Marquis X Turkey grown close to it several years before.

to the attacks of the old form of ten years ago. It also makes the breeding of resistant wheats more difficult, as the new wheat must be resistant to all smut forms, to be effective in controlling the disease.

In recent years the dry treatments (principally copper carbonate) have largely superceded the wet treatments (bluestone and formaldehyde) because of the difference in the amount of seed injury. The wet treatments often kill from one-third to one-half of the seed, whereas most of the dust treatments cause little or no injury. Copper carbonate controls smut practically as well as bluestone or formaldehyde and gives better yields and better control of weeds due to the thicker and more uniform stand.

The rapid increase in the quantity of the resistant varities, Albit and Ridit, grown the last two years has done much to reduce the amount of smut produced in the Pacific Northwest. The fact that Albit is quite susceptible to three of the new smut forms and somewhat susceptible to two others makes it very necessary to treat the seed as a protection against increasing the prevalence of these new forms.

SPRING WHEAT

In spring-seeded wheat any smut which appears in the crop generally originates from the spores of the smut fungus carried on the seed, since wind-blown smut of the previous season does not live through the winter. Seed treatment may or may not be necessary, the need for seed disinfection depending upon two factors: *first,* the resistance of the variety; and *second,* upon the spore-load of the seed grain.

Resistant Varieties

Marquis is the most resistant of any of the spring wheats commonly grown, and is often sown without treating the seed, with satisfactory results. It represents from 10 to 20 per cent of the spring wheat grown in Washington, but is not so well adapted to certain sections as Baart, Federation or Jenkin.

There are several new introductions and hybrids that are immune or highly resistant to the various smut forms tested at Pullman and at the same time show promise from the standpoint of yield and quality. One

of the best is a cross between Baart and Ridit. Another is Lutescens, a variety from Russia. These are both red wheats. The best white wheat in respect to both resistance and yield is a cross between Martin and Marquis. Hope, a hard red wheat adapted to sections of Minnesota and North Dakota, was immune from all seven forms of smut in the tests at Pullman in both 1928 and 1929, but the yield is only about one-half that of our best local varieties. Spring Alaska is also highly resistant to all forms and yields eleven bushels per acre more than Hope, but it is still considerably below the standard varieties in yield.

To sum up, there are promising resistant spring wheats, but none that are to be recommended as yet in place of the commonly grown susceptible varieties.

Relation of Spore-Load to Need for Disinfection

In the case of seed wheat that is visibly smutty, that is, if it shows a faint dark coloration in the brush due to the presence of smut spores that can be readily detected with the naked eye, the spore-load will amount to 4000-5000 spores per grain of wheat. Such seed if used without seed disinfection might produce five or more per cent of smut and should invariably be treated if used. When the spore-load is below visibility, the amount of smut produced in the crop will vary from none to traces or in a few cases to two or three per cent. The actual per cent of smut which appears in the crop will depend upon the average number of spores to the grain and upon their viability. Experience has shown that farm-stored wheat does not show smut equal to similar wheat that is artificially smutted in the spring with a corresponding load of smut. This is caused apparently by the loss of vitality of many of the smut spores that spend the winter period in the loose form on the surface of the grain. This relation of the spore-load of farm samples of spring wheat to the per cent of smut appearing in the crop is illustrated by the results presented in Table 2. In fifty-nine samples seeded without disinfection, thirty-six samples with spore-loads from 18-6087 showed no smut in the crop. The variability in the other twenty-three was marked, but in only two did the per cent of smut in the crop exceed 3.74. In most samples showing spore-loads of over 5000 the per cent of smut was small as may be illustrated by the following:

Spore-load— 7232—Per cent of smut 2.27.
Spore-load— 8188—Per cent of smut 1.00.
Spore-load—12167—Per cent of smut 2.5.

Table 2. Relation of Spore-Load of Farm Samples of Spring Wheat to the Per Cent of Smut Appearing in the Crop

Variety	No smut		Smut		
	No. of samples	Range of spore-load	No. of samples	Range of spore-load	Range of smut per cent
Bluestem	6	21-682	7	45-1320	0.5-0.9
Baart	8	41-509	5	477-20176	0.94-20.00
Jenkin	2	3462-6087	4	799-12167	0.53-2.27
Hybrid 143	2	87-645	4	1185-8188	1.00-3.74
Marquis	18	18-842	3	64-478	0.5-0.8
Total	36		23		

Seed Treatment Effective for Spring Wheat

Many different fungicides have been shown to be effective in preventing smut in spring-seeded grain, but only a relatively small number have come into general farm use: namely, bluestone, formaldehyde and copper carbonate. The comparative effectiveness of these three treatments based on a large number of tests is shown in Table 3. From these tests it may be noted that formaldehyde stands first in the percentage of plantings showing perfect control, with bluestone nearly its equal. Either of the wet treatments are more likely to give perfect control than copper carbonate, especially if the seed is carrying a heavy load of smut (Table 4). This may be illustrated by some tests with light, medium and heavily smutted seed, ten lots in each series. With copper carbonate the light and medium smutted lots showed perfect control, while the ten that were heavily smutted showed an average of 0.93 per cent of smut. Even with the copper carbonate the amount of smut appearing in the crop when perfect control is not obtained varies from traces to only 2-3 per cent. The convenience of the copper carbonate dust treatment combined with the complete elimination of seed injury resulting in better stands is sufficient justification for the adoption of this fungicide as one of the standard seed disinfectants for spring grain.

In case of visibly smutted seed it will be advisable to use at least 3 ounces per bushel, but grain not visibly smutted should be adequately protected by 2 ounces per bushel.

Table 3. The Comparative Value of Standard Formaldehyde, Bluestone and Copper Carbonate Treatments in the Prevention of Smut in Spring Wheat.

Treatment	Total No. of tests	No. giving perfect control	Maximum per cent smut	Per cent of tests giving perfect control
Formaldehyde	36	34	0.2	94.4
Bluestone	14	12	0.3	85.7
Copper carbonate	48	35	2.3	72.9

Table 4. The Comparative Per cents of Smut with Two Varieties Treated with a Typical Fifty Per cent Copper Carbonate and the Best Seventeen Per cent Compound.

Spore load	Dosage of dust oz. per bu.	Jenkin		Bluestem	
		50	17	50	17
Light	2	0	0	0	0
"	3	0	0	0	0
"	4	0	0	0	0
"	5	0	0	0	0
"	6	0	0	0	0
Medium	2	0	0	0	0
"	3	0	0	0	0
"	4	0	0	0	0
"	5	0	0	0	0
"	6	0	0	0	0
Heavy	2	0	.89	1.91	1.63
"	3	0	.81	.88	1.71
"	4	0	.79	0	.47
"	5	0	1.1	0	0
"	6	0	0	.66	1.9

Checks—Jenkin, Light, medium and heavy smut 12.01, 57.4, 65.6.
Bluestem, Light, medium and heavy smut 11.3, 55.4, 70.8.

The value of increasing the amount of copper carbonate per bushel to at least 3 ounces may be illustrated by a series of tests as shown in Table 5.

Table 5. **The Comparative Effectiveness of 2 and 3 Oounces of Copper Carbonate per Bushel in Treating Heavily Smutted Seed.**

Lot Number	Per cent of smut in the crop	
	2 oz. per bu.	3 oz. per bu.
1	0.9	0
2	0.89	0
3	1.91	0.88
4	2.3	0.66
5	1.2	0.94
6	1.32	0
7	5.88	0.83
8	0	0
9	0.6	0.71
Average	1.66	0.45

Many different brands of copper carbonate are on the market, but these fall into two groups: (1) The pure copper carbonate or those containing 50 per cent or more of metallic copper; and (2) mixtures into which other inert materials have been incorporated with the result that they carry only 17-20 per cent of metallic copper.

The performance that may be expected with different standard brands in comparison with formaldehyde and bluestone is shown in Table 6. Of the nine pure copper carbonates tested, none were markedly superior, while all were sufficiently effective to justify their use in farm plantings. The 17 per cent mixtures were more variable, one ranking in effectiveness with the 50 per cent series, while the others were somewhat less effective. In all of our experimental tests with the mixtures containing less copper than the pure copper carbonates, the protection has not been in proportion to the metallic copper contained in comparison with the pure copper carbonate. Apparently the fungicidal action of the copper has been increased by the incorporation of the inert ingredients. It would appear from the results shown that the amount of copper carbonate compound to be used per bushel should be increased to at least four ounces unless a brand of known performance is being used.

Table 6. Relative Value of Different Brands of Copper Carbonate

Based on 12 tests for each brand: 2 ozs. and 3 ozs. per bu. on light, medium, and heavy smut of Jenkins and Bluestem.

No.	Brands	Av. % smut	No. of the twelve tests giving perfect control.
1	Pure copper carbonate ..... 50% +	0.24	9
2	Pure copper carbonate	0.53	6
3	Pure copper carbonate	0.54	8
4	Pure copper carbonate	0.52	7
5	Pure copper carbonate	0.99	5
6	Pure copper carbonate	0.17	7
7	Pure copper carbonate	0.29	7
8	Pure copper carbonate	0.32	7
9	Pure copper carbonate	0.16	9
10	Copper carbonate compounds.... 17% +	1.05	4
11	Copper carbonate	.85	6
12	Copper carbonate	2.09	2
13	Copper carbonate	1.12	2
14	Formaldehyde 1-320, 10 min.....	0	12
15	Bluestone 1-5, 10 min.....	0.9	8
16	Untreated samples	27.5	..

Light—7500 spores per grain.
Medium—87173 spores per grain.
Heavy—84257 spores per grain.

Tests With Gas Grain Treater

A modified formaldehyde treatment by the use of a gas grain treater has recently been offered to the wheat growers and has been used to a limited extent in farm practice. The principle of this treatment is that paraformaldehyde, a white powder, is volatilized by heat to form formaldehyde gas which is forced into a sack of grain under pressure. This treatment has been tested with the results shown in Table 7 (11). In this treatment there was no protection against smut in the grain taken from the periphery of the sack, the average per cent of smut for the three plantings from the periphery being slightly in excess of the per cent of smut for the three similar untreated samples. The grain from the center of the sack close to the inlet pipe showed a much poorer control of the smut than was obtained with the standard formaldehyde treatment (average 12.5 per cent as contrasted with 1.7 per cent). It should also be noted that the gas treatment had no effect on the percentage of germ-

ination of the grain from the periphery of the sack, but that grain from the center of the sack showed a pronounced reduction in germination which was increased greatly when seeding was delayed for 24 hours or more. The reduction in germination was more marked than in the case of the grain treated by the standard formaldehyde method and held for similar periods before seedings. These results on germination were also confirmed by similar plantings made in the greenhouse.

It is recognized that the cause of severe injury to germination of formaldehyde-treated wheat when seeded in dry soil is the formation of paraformaldehyde. In the case of the gas treatment it seems that the formaldehyde gas recondenses on the grain as paraformaldehyde, thus causing the reduced germination shown in the tests.

Table 7. Field Tests of the Comparative Effectiveness of Treatment by the Gas Grain Treater and the Standard Formaldehyde in the Prevention of Stinking Smut
Jenkin Seeded April 29, 30 and May 3, 1929

Kind of treatment		Time of planting after treatment	No. of plants in test	Average % of smut in triplicate plantings
Check No treatment		1 hr.	235	62
Gas grain treater	Sample from center of sack	1 hr.	207	11
	Sample from periphery of sack	1 hr.	260	69
Standard formaldehyde 1-320 for 10 minutes		1 hr.	228	9
Check No treatment		24 hrs.	259	55
Gas grain treater	Sample from center of sack	24 hrs.	140	24
	Sample from periphery of sack	24 hrs.	250	64
Standard formaldehyde 1-320 for 10 minutes		24 hrs.	164	3.7
Check No treatment		4 days	269	43
Gas grain treater	Sample from center of sack	4 days	96	2.4
	Sample from periphery of sack	4 days	251	42
Standard formaldehyde 1-320 for 10 minutes		4 days	154	1.5

1 Manufactured by the Gas Grain Treater Co., Portland, Oregon.

	Total No. plants	Av.% smut
Check, No treatment	763	53.3
Gas treater, center of sack	443	12.5
Gas treater, periphery of sack	761	58.3
Formaldehyde, standard	546	1.7

Other Seed Disinfectants

During the past ten years many seed disinfectants have been tested. Some have given very poor control, while others have yielded protection comparable to the standard formaldehyde, bluestone and copper carbonate treatments. The following have given satisfactory protection:

Wet treatments—0.25% solution in water for 30 minutes (1-400):

Uspulun, Germisan, Super-Kalimat, Tillantin B, Bayer Compound

Dust treatments—2-4 ozs. per bushel according to spore load:

Bayer Dust, Semesan, Tutan, Wa Wa Dust, Trockenbeize 25 III, Abavit B, Ceresan, Vitrioline, Copper oxalate (Table 8).

The majority of these compounds are either much more expensive than formaldehyde, bluestone or copper carbonate or are not generally available on the market. (For results with ceresan, see seed treatment for winter wheat).

Table 8. The Per cent of Smut in Various Wet and Dry Treatments

Fungicide	No. of tests	Per cent of smut from treatment			Average per cent of smut for untreated checks
		Minimum	Maximum	Average	
Uspulun	12	0	0.8	0.16	26.8
Germisan	6	0	0	0	22.5
Super-Kalimat	5	0	0.76	0.15	22.5
Tillantin B	2	0	0	0	33.9
Bayer Compound	2	0	0.2	0.1	33.9
Bayer Dust	7	0	2.6	.99	17.2
Semesan	16	0	6.89*	1.49	26.8
Tutan	2	0	0.6	0.3	23.1
Wa Wa Dust	5	0	0.39	0.07	17.2
Trockenbeize 25 III	2	0	1.3	0.7	23.1
Abavit B	2	0	0	0	23.1
Copper oxalate	2	0	0	0	43.3
Vitrioline	2	0.4	0.4	0.4	12.3

* In very heavily smutted seed.

WINTER WHEAT

The control of bunt in fall-seeded grain presents an entirely different problem from control in spring wheat. In addition to the smut spores carried on the seed, fall-seeded wheat will be subjected to danger of infection from myriads of wind-blown spores which were deposited in the summer fallow during the previous harvesting and threshing season. It is this so-called "smut shower" (4, 5) which necessitates methods other than seed disinfection for the control of bunt in winter wheat. The standard seed disinfectants will kill the seed-borne spores in winter wheat just as effectively as in spring wheat, but the effect of these treatments on the amount of smut from soil contamination is either none or at best only poor. In experimental plantings of carefully treated seed the per cent of smut produced in the crop has varied from only a small per cent to even 40 to 60, depending upon location, season, time of seeding, or other factors. The problem then in fall-seeded grain is how to reduce the infection from soil contamination to a minimum.

The principal lines of control that are available will be discussed under the following heads: (a) The use of resistant or immune varieties; (b) seed disinfection; and (c) cultural practices. Before discussing these, brief consideration will be given to the effect of bunt on yield.

Effect of Smut on Yield

The question is sometimes raised as to whether the percentage of smutted heads in a field represents the actual percentage of reduction in yield. The smutted heads are usually smaller, shorter and lighter than normal heads filled with grain. On the other hand, smut is much higher in nitrogen than wheat (3.68 per cent compared with 1.8 per cent), and, although the plants are smaller and the heads lighter, there is probably as much nitrogen taken from the soil by the smutted plants as by the normal ones.

To determine this point, along with others a series of 53 tests were analyzed (Table 9).

Table 9. Effect of Smut on Yield

No. of tests	Per cent of smutted heads	Av. % smut	Yield Bu. per A.	Comparative yield
24	1-30	20.8	45.8	100
29	31-71	46.0	35.2	77
Difference		25.8	10.6	23

An average difference of 25.8 per cent of smutted heads made a difference of 23 per cent in yield. The coefficient of correlation between smut and yield was—.713± .0455, which is nearly 16 times the probable error.

The conclusion from a careful study of these experiments is that the percentage of smutted heads is a fairly accurate indication of the actual loss to the farmer.

The thickness of the stand, which varied from 42 to 100 per cent, had but slight effect on either yield or smut as shown by the low coefficients of correlation, .155± .09 and .1715± .0899 respectively.

Use of Resistant or Immune Varieties

The propagation of resistant varieties seems to be one of the most hopeful means of reducing smut losses. When certain varieties of winter wheat are blackened with viable smut spores and sown on dates from September 15 to October 20, they show striking differences in susceptibility as may be illustrated by Table 10.

Table 10. Percentage of Smut Produced on Various Fall-sown Wheats for the Eight-year Period—1921 to 1928

Variety	1928	1927	1926	1925	1924	1923	1922	1921	Av.
Jones Fife	82	81	91	45	20	92	85	94	74
Hybrid 128	65	88	84	55	18	80	91	94	72
Red Russian	58	54	91	39	22	90	86	87	66
Triplet	67	82	94	39	14	82	70	74	63
Fortyfold	48	68	71	31	25	62	74	58	55
Kanred	20	32	8	3	2	12	11	23	14
Turkey	6	13	2	0.2	0.4	0.1	4	11	5
Kharkof	10	5	2	0.6	2	0.3	1	13	4
White Odessa	0	0	0.6	0	0	0	0	....	trace
Ridit	0	0	0	0	0	0	0	0.3	trace
Albit	0	0	0	0	0	0.2	....	....	trace
Hussar	0	0	0	0	0	0	0	0	0
Martin	0	0	0	0	0	0	0	0	0

This tabulation shows that five varieties are quite susceptible, producing more than 50 per cent of smutted heads as an average of eight years. Three others would be classified as highly resistant, and the five others are practically immune.

Turkey, Ridit and Albit are now grown on more than half the winter wheat acreage, and no doubt are doing much to lessen the amount of smut produced. The general planting of such varieties should practically eliminate the form of smut represented in these tests.

The new physiologic forms of smut mentioned in the introduction complicate matters, for they have been spreading rapidly in recent years, and some of them attack Turkey and Albit severely. Ridit remains highly resistant to all forms tested thus far. The figures obtained in 1929 with the old form of smut (T 1) in comparison with two of the more virulent of the new forms are shown (Table 11).

Table 11. Comparison of the Old Strain of Smut with Two New Strains

Variety	Per cent smut obtained from inoculum of		
	T1	T3	L7
Turkey	6	2	71
Ridit	0	0	14
Albit	0	77	72

Turkey is resistant to form T3 while Albit is highly susceptible (77 per cent of smutted heads). Each strain produces more than 70 per cent of smut when spores from form L7 are used to blacken the seed. L7 also attacks Ridit five times as severely as any other form. Hohenheimer, on the other hand, did not produce a trace of smut from the L7 or T3 inoculum. Hohenheimer is a winter-hardy, soft-red wheat received recently from Germany. Crosses between Ridit and Hohenheimer have been made, and it is expected that some of the offspring will contain a concentrated heritable resistance to more smut forms than any known bread wheat at the present time. Such a wheat, combined with other qualities of economic importance should go far toward reducing the smut losses in the regions to which it may be adapted. In the meantime, while such a new variety is being developed Ridit might well be grown still more extensively in the Palouse and Walla Walla Districts where smut is a major problem. It yields well, is a good combine wheat, and grades as Hard Red Winter on the market.

Seed Disinfection for Winter Wheat

Except in the case of highly resistant or immune varieties the disinfection of seed wheat for fall planting should be generally practiced. It should be pointed out that formaldehyde which is completely effective for spring wheat when only seed-borne smut must be guarded

against is less effective than a copper fungicide when soil contamination is an additional source of smut infection. A comparison of the effectiveness of the standard formaldehyde and the standard bluestone treatments is presented in the appended tabulation covering plantings through a period of years with different varieties (Table 12). The average of thirteen different plantings gave 29.1 per cent of smut in the crop with formaldehyde as contrasted with 17.4 per cent of smut when bluestone was used. It may be noted that bluestone gave a consistently better protection except in two plantings of the highly resistant Turkey in which the amount of smut was very low and in one of Red Russian. In one of these the per cent of smut was equal, while in the others the bluestone treatments were but 0.5 per cent and 0.6 per cent better than the fomaldehyde. Since formaldehyde has little or no effect in the prevention of smut from soil contamination it may be assumed that the

Table 12. The Comparative Value of the Standard Formaldehyde and Bluestone Treatments in Prevention of Smut in Winter Wheat Seeded in Summer Fallow

Variety	Spore-load	Per cent of smut in crop		
		Standard formaldehyde 1-320-10 min.	Standard bluestone 1-5 - 10 min.	Increased protection from bluestone
Hybrid 143	From field showing 88% smut heads	78.1	62.0	16.1
Hybrid 143	From field showing 88% smut heads	54.2	38.1	16.1
Winter Fife	From field showing 66% smut heads	8.3	0.5	7.8
Winter Fife	From field showing 66% smut heads	12.4	2.4	10.0
Hybrid 128	Clean seed	18.6	10.5	8.1
Turkey	Clean seed	0.6	0.6	0.
Red Russian	Clean seed	5.7	3.8	1.9
Hybrid 128	Clean Seed in artificially contaminated soil	42.0	6.0	36.0
Turkey	Clean Seed in artificially contaminated soil	4.8	4.3	0.5
Red Russian	Clean Seed in artificially contaminated soil	28.1	27.5	0.6
Hybrid 128	Clean seed	26.6	1.15	15.1
Hybrid 128	Clean seed	27.7	16.3	11.4
Hybrid 128	Clean seed	49.6	25.1	24.5
Hybrid 128	Clean seed	50.9	35.6	15.3
	Average	29.1	17.4	11.7

difference between the per cent of smut in the bluestone treatments and the formaldehyde treatments represents the protection afforded by the bluestone treatment against infection from smut spores in the soil. In the case of the bluestone treatment there is left upon the seed a residue of copper sulphate, which may later dissolve in the soil moisture around the seed and thus afford some protection, while the volatile formaldehyde soon disappears and so can have but little effect upon smut spores that were in the seed bed.

The question may also be raised of the comparative effectiveness of the copper carbonate dust treatment and the standard bluestone dip. This may be answered by the results presented in Table 13. The average for 18 different seedings shows a slightly better performance for bluestone-treated seed. It should be pointed out, however, that in many parallel seedings the advantage has sometimes been in favor of one and sometimes in favor of the other. This may be expected if two practically equal treatments are contrasted since pairs of untreated checks have shown differences in the per cent of smut appearing in the crop from slight to as much as 12-14 per cent. It is, therefore, not safe to draw conclusions from single parallel plantings as to the superior protective effect of a given disinfectant. On the basis of our experimental tests and the results obtained in general farm practice it seems safe to conclude that bluestone and copper carbonate are nearly equal in protective value.

There appear to be three factors which affect the effectiveness of the copper carbonate dust treatment: (a) the spore load carried by the grain; (b) the degree of soil contamination; and (c) the per cent of soil moisture during the period of germination and emergence of the seedlings. Under conditions of heavy spore load, maximum soil contamination and abundant soil moisture, blusetone treatment may be expected to give the better results, while with moderate spore load or soil contamination the value may be about equal but with moderate soil moisture the copper carbonate appears to give its best performance. These conclusions are based on periodic plantings extending from the first of September to early November. As an illustration, the results obtained with clean seed planted in summer fallow at a period of maximum soil contamination and high soil moisture may be cited:

Seeded September 29, the bluestone treatment gave 13.4 per cent smut, the copper carbonate 26.3; October 6, gave 22.8 per cent for the bluestone and 27.2 per cent for copper carbonate. Further experimental data on the relation of soil moisture to the effectiveness of the copper carbonate are desirable, but it seems probable that the slow solubility of the toxic salt will be more likely to yield an inhibiting concentration in soils with light or moderate soil moisture, but too great a dilution in the presence of abundant moisture. This is offered as a partial explanation for an apparent greater effectiveness of copper carbonate in the case of early plantings over the results obtained with some later seedings.

Table 13. Comparison of Bluestone, Copper Carbonate and Formaldehyde Fall Seedings

Seed treatment	No. 1 1922		No. 2 1922		No. 3 1923	
	No. of seedling	Av. % smut	No. of seedlings	Av. % smut	No. of seedlings	Av. % smut
Bluestone	4	15.45	10*	9.5	4	31.25
Copper carbonate	4	17.3	10	9.3	4	40.95
Formaldehyde	2	27.7	10	12.7	2	50.21
No treatment	4	51.3	10	24.0	4	64.92

* Periodic from Sept. 1 to Nov. 3.

An organic mercury disinfectant known as *ceresan*[1] has recently been placed on the market. This is a dust for application in the same way as copper carbonate, and it has the same value as copper carbonate in relation to the elimination of seed injury. A comparison of the effectiveness of ceresan and copper carbonate on fall seedings of heavily smutted seed, using both of the species of smut, is presented in Table 14. The dusts were used at the rate of 3 ounces per bushel and also all that would stick to the seed. The two dusts appear to be practically equal in effectiveness at the rate of 3 ounces, ceresan showing an average of 5.75 per cent and copper carbonate an average of 6 per cent for the two species of smut. Since the relatively low per cent of smut in the treated lots indicates a light soil contamination, the comparative value of the two treatments under conditions of high soil contamination still remains uncertain. It seems probable that ceresan may take its place as a standard disinfectant for seed wheat, the main retarding factor being a higher cost.

[1] Bayer-Semesan Company, Inc., 105 Hudson St., New York City.

Formaldehyde cannot be recommended for the treatment of winter wheat, since it has been repeatedly shown to be inferior to bluestone or copper carbonate in its protection against infection from smut in the soil. It has the added objection of being unsafe for use if the grain is to be seeded in the dust. (15) The principal objections to bluestone are: first, that it is a wet treatment and cumbersome to carry out; and second, the constant danger of seed injury. This may, however, be greatly reduced by the use of the lime bath or by presoaking (8). There is no seed injury with either copper carbonate or ceresan and the treatment is easy to apply by the use of either homemade or commercial dusters. The seed grain may be dusted at any time and stored for use, the germination improving with age over that of untreated seed (6).

Table 14. Comparison of Ceresan and Copper Carbonate in Fall Seeding of Heavily Smutted Hybrid 128

Treatment	Dosage per bushel	Rough-spored species (T1) % smut	Smooth-spored species (L7) % smut	Average % smut
Ceresan	3 ozs.	8.5	3.0	....
Ceresan	Maximum load	5.5	1.5	4.6
Copper carbonate	3 ozs.	9.	3.0	....
Copper carbonate	Maximum load	12.5	1.5	6.5
None	None	37.5	36.5	....
None	None	66.5	38.5	44.8

Relation of Cultural Practices to the Amount of Smut Appearing in the Crop

Various cultural practices have a marked influence on the amount of smut which will appear in a given crop. Among these may be mentioned: depth of seeding; type of seeding as broadcasting, surface drills or trenching; replowing or turning of summer fallow previous to seeding and date or time of seeding (7). Shallow seeding gives less smut than deep seeding, broadcasting less than drill seeding, trenching less than surface drilling, and replowed summer fallow less than the unturned summer fallow, but modification of farm practices in these respects is rarely practical. Of these the most value may be hoped for from trench seeding in regions in which the topography of the country will permit this type of seeding. Throughout the Inland Empire principal thought and emphasis should be given to the date or time of seeding.

per cent of smut in the crop, emphasis should be given to three fundamental features: (1) The relation of the temperature of the soil at the time of seeding and during the following days when the seedlings are emerging to the possibility of infection; (2) the time of seeding with reference to the period when the maximum of soil contamination will be encountered; and (3) per cent of soil moisture at time of seeding and during the period of emergence of the seedlings.

The temperature of the soil at time of seeding and during the early period of growth of the young seedlings affects the amount of smut which will appear in the crop. There is a maximum temperature above which no infection will occur, an optimum at which the highest percentage of infection will result and a minimum below which no infection is possible. As the temperature is raised above the optimum the percentage of infection becomes less and less and as the temperature drops below the optimum there is a gradual decrease in the percentage of infection. The exact temperature range or the location of minimum, optimum and maximum points seems to show some variation, possibly influenced by host susceptibilities and species or strains of smut, but for present purposes it may be noted that little or no infection will occur if the soil temperature is above 65° F. (7), although in some cases very light infections have resulted with temperatures ranging as high as 77°-82° F. (9). Temperatures from 45° to 54° F. are very favorable for infection with the optimum close to 45° F. Below 40° F. very little or no infection will result, but the exact minimum has not been determined.

Field observations and experiments under controlled conditions (7, 9) have shown that the less moisture there is in the soil at the time of germination of the wheat, the less smut there will be in the crop. For example, seeding in heavily smutted soil containing 15 to 20 per cent moisture under favorable temperature conditions yielded 8 to 26 per cent of smut, while with 25 to 30 per cent of moisture the per cent of smut reached 62 to 68. With a moisture content of 8 to 12 per cent no smut developed, which shows that there is a low percentage of soil moisture which will permit the germination of wheat with the escape of infection even though an abundance of smut spores may be present in the soil and on the seed. This relation of moisture to smut infection will explain the numerous experiences in which seeding in the dry

or previous to a rain has given less smut than seeding after a rain. It is probably also the moisture relation which is in the main responsible for less smut in shallow than in deep seeding

The summer fallow fields of the Inland Empire owe their contamination with smut to wind-blown spores which begin to fall with the first threshing operations. This spore fall or "smut shower" is light at the beginning, increases to a maximum and later gradually subsides with the cessation of threshing operations (5). The prevailing winds are such that there is a drifting of the smut spores from the regions of early harvest to the regions of later harvest, with the result that summer fallow fields of eastern Washington and adjacent Idaho are very heavily contaminated with smut by the time the smut shower has subsided. The exact time when the maximum of the spore fall will be reached varies somewhat with the season, but in eastern Washington it may be slightly before or slightly after the middle of September. Field experiments have shown that the maximum infective power of the wind-blown smut generally falls eight to ten days following the period of maximum spore fall. From the relation to exposure to soil smut, plantings during the early part of the season might be expected to escape with only light infection, while with plantings in late September or early October the chances of encountering a heavy soil contamination are great. It may be noted further that smut spores which are present in moist soil germinate in a few days and throughout succeeding weeks gradually lose their infective power. The infective possibility from the soil smut may be expected to decline gradually from a date eight or ten days beyond the maximum of the smut shower until the end of the season, unless the soil is too dry for germination of the spores.

The Relation of Time of Seeding to the Per Cent of Smut Which Will Appear in the Crop

The effect of time of seeding on the per cent of smut that will appear in the crop may be best presented by the selection of three graphs showing the results of periodic seedings of treated seed beginning early in the planting season and extending into late October or early November. These will give about the variations which may be expected (Fig. 2). It may be noted that seedings made during the last of August or early in September give a relatively low per cent of smut with an

increase with some fluctuations until early in October when the maxima are reached. Following the maximum there is a general decline with the complete elimination of smut in the late plantings. The maxima were as follows: 42 per cent for October 2, 1916; 14 per cent for October 3, 1918; and 28 per cent for October 6, 1922. The year 1916 represents a season very favorable to smut with a high maximum and the customary decline for the later dates but the plantings of October 30 and later winter-killed, so that there were no late fall plantings that were smut-free. The season of 1918 presented about the extreme of

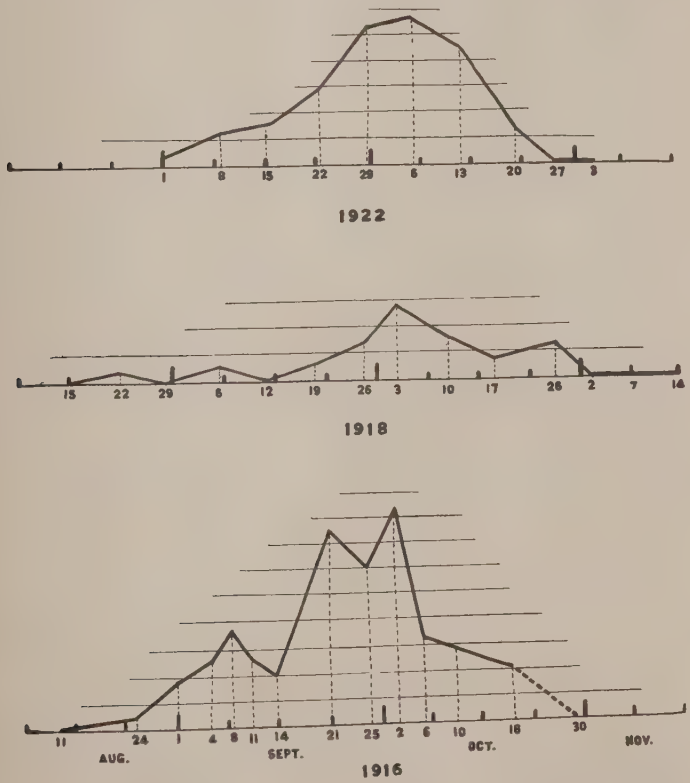

Fig. 2. Graphs showing the per cents of smut in periodic plantings for three different year.

unfavorable conditions for smut infection, some of the early plantings being entirely smut-free, while the per cent of smut never rose above 5 until September 26, with the low maximum following soon after. It should be noted that the three November seedings were entirely free from smut. In 1922 there was a fairly rapid increase in smut in the plantings after the 15th of September with very favorable conditions continuing for three or more weeks, with a maximum that is more nearly typical of average seasons in the eastern counties of the state.

The reasons for the results shown by the three graphs may now be briefly discussed. The low per cent of smut in the early plantings is apparently caused by three factors: (1) The high soil temperatures which generally prevail at that season of the year; (2) a moisture content of the soil that is not the most favorable for maximum infection; and (3) the summer fallow had not yet reached its maximum of con-

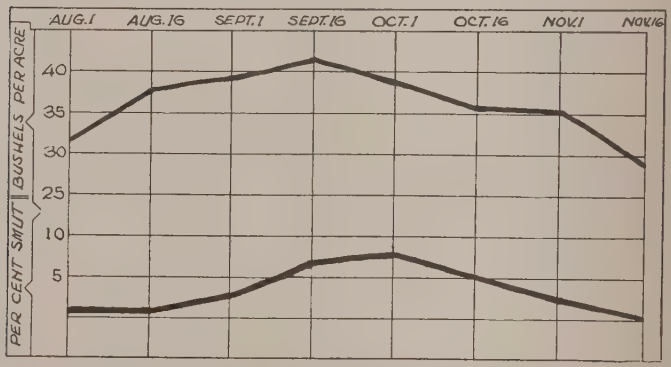

Fig. 3. Effect of date of seeding on the per cent of smut and yield based on the average for nine years (After Schafer, Gaines and Barbee).

tamination by wind-blown smut. The conditions are generally favorable for heavy smutting in late September and early October for these reasons: (1) The temperatures which normally prevail at that season of the year are very favorable to infection; (2) the moisture content of the soil is more likely to approach the optimum or to be favorable for maximum infection; and (3) the maximum infective power of the wind-blown smut is reached during the period. The reduction in smut

during the last part of the planting season appears to be due in the main to two factors: (1) The low temperatures which normally prevail are generally too low for high infection; and (2) many of the smut spores which fell on the soil in the earlier part of the season have germinated and their infective power has been lost.

During the period from 1917 to 1925 periodic planting of field plots were made at bi-monthly intervals on the first and the sixteenth, using two varieties, Hybrid 128 and Red Russian, this giving 18 season-variety tests (14). In four cases the maximum per cents of smut were recorded previous to October 1, in seven the maxima were on October 1, while the remaining seven were later than October 1. The plots were also threshed for yield and the averages for the nine-year period are presented in the accompanying graph (Fig. 3). With Hybrid 128 the highest yields were obtained on September 16 or earlier in seven of the years with only two highest yields at later dates. With Red Russian the highest yields were obtained on September 16 or earlier in five of the nine years, and four highest yields after September 16. On the basis of results shown in these periodic plantings it can be safely assumed that the period from September 1 to the middle of the month is likely to give relatively low per cents of smut, and there is more than an even chance that the highest yields possible for the season will be obtained if the seeding is done on September 16 or slightly earlier. Very early seedings show but little smut, but the yields are poor, while late seedings which also give a reduction in smut are frequently low in yield and have the added objection of liability to winter killing.

SUMMARY

1. The problem of bunt control in Washington has been made more difficult by the establishment in recent years of the smooth-spored species, *Tilletia levis,* throughout the wheat districts of the Inland Empire.

2. Control has also been complicated by the appearance of physiological strains of bunt, three of *T. tritici* and four of *T. levis,* since varieties resistant to certain strains are very susceptible to others.

3. Commercial immune varieties of spring wheat are not yet available, but Marquis is the most resistant of any commonly grown. There are other promising spring varieties, but these must be improved before they can take the place of the commonly grown susceptible varieties.

4. Seed disinfection is a satisfactory control for spring-seeded wheat; whether treatment is necessary will depend upon the resistance of the variety and the spore load of the grain.

5. Of the three common seed disinfectants for spring wheat formaldehyde has given the highest percentage of perfect control tests, with bluestone second and copper carbonate third.

6. There were no striking differences in the effectiveness of the different brands of pure copper carbonate, but some of the compounds are not equal in their protection to the pure copper carbonates.

7. Treatments with the gas grain treater have not been satisfactory because of seed injury and failure to protect the wheat from infection. Seed in the center of the sack was severely injured, while grain from the periphery of the sack showed no reduction in smut.

8. Control of smut in winter wheat is complicated by the heavy soil contamination resulting from wind-blown spores which are generally present in the summer-fallow fields at time of seeding.

9. Data are presented to show the pronounced effect of smut on the yield, with the conclusion that the percentage of smutted heads is a fairly accurate indication of the actual loss to the farmers in grain and money.

10. Since winter wheats show all gradations in susceptibility from high infection to complete immunity, the selection of resistant varieties offers a valuable means of reducing losses. The most promising are Turkey and the new varities, Albit and Ridit, especially the latter which is highly resistant to all of the physiological forms tested.

11. Seed disinfection does not prevent smut in winter wheat but should be generally practiced except in immune or highly resistant varieties as it will prevent infection from seed-borne spores and aid in reducing the infection from soil contamination.

12. Bluestone is much more effective than formaldehyde for winter wheat, the latter not being recommended. Copper carbonate has not given protection quite equal to bluestone, but the differences are not great. Limited tests of the new organic mercury disinfectant, ceresan, indicate that it is equal to copper carbonate in protecting wheat from infection.

13. The per cent of smut appearing in the crop is influenced by various cultural practices, but greatest emphasis should be given to time of seeding.

14. The fundamental features which influence the per cent of smut at any planting are: (1) Temperature of the soil; (2) moisture of the soil; and (3) the degree of soil contamination. Little infection results at temperatures above 65° F. or below 40° F., but 45° to 50° F. is very favorable for infection. Low moisture of the soil is unfavorable to infection, while moderate moisture promotes infection. The highest infection may be expected following the peak of the smut showers, when there is a maximum of soil contamination.

15. Early seedings previous to September 15 are generally low in smut or entirely free, while seedings between September 15 and early October are very frequently heavily smutted, but there is generally a reduction in infection during the last part of the planting season.

16. If the seeding is done on September 16 or slightly earlier, there is an even chance that the highest yields possible for the season will be obtained with a practical certainty that the amount of smut will be low. Late seedings will give low smut, but there is much danger of winter killing and yields are generally low. Seeding between September 15 and early October will guarantee a high percentage of smut with but slight chance of maximum yield.

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